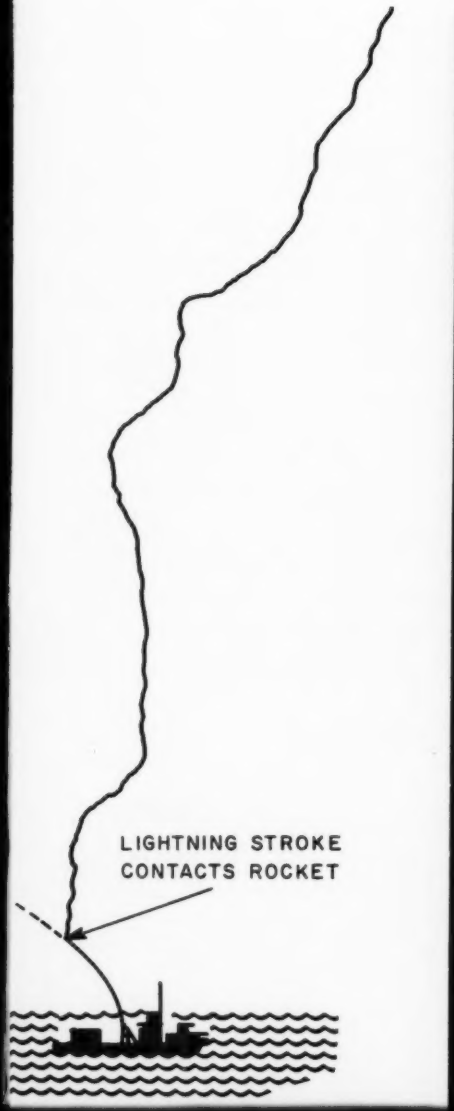
NAVAL RESEARCH

REVIEWS

APRIL 1970



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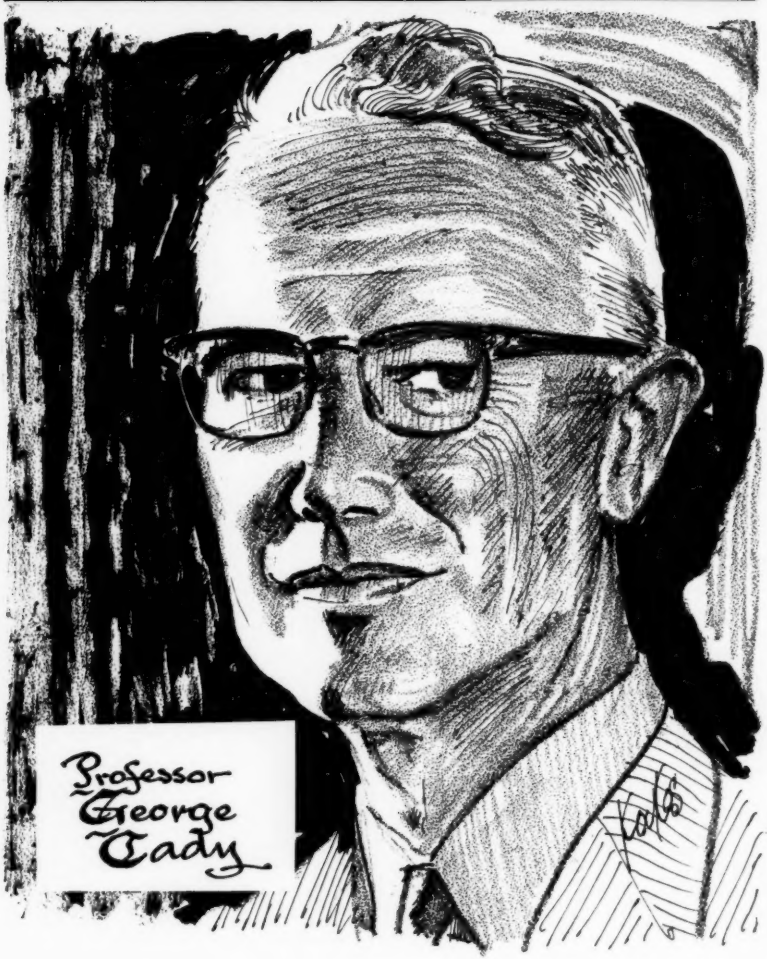
Portraits in Science



FLUORINE AND CADY ARE ALMOST SYNONYMOUS. BECAUSE OF DR. CADY'S PIONEERING RESEARCH INTO FLUORINE CHEMISTRY, A LARGE FAMILY OF INGREDIENTS FOR HIGH ENERGY APPLICATIONS HAS BEEN DEVELOPED. DR. CADY HAS BEEN AN ONR RESEARCH INVESTIGATOR FOR MANY YEARS. HIS DISCOVERIES COVER INORGANIC COVALENT FLUORINE CHEMISTRY AND VARIOUS FORMS OF CATALYTIC FLUORINATION. OF PARTICULAR SIGNIFICANCE TO ACADEMIC FLUORINE RESEARCH ARE THE LOW-COST TECHNIQUES WHICH DR. CADY DEVELOPED. TODAY DR. CADY IS PROFESSOR OF CHEMISTRY AT THE UNIVERSITY OF WASHINGTON.

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Lightning and Rockets: Some Implications of the Apollo 12 Lightning Event

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INTRODUCTION

The Apollo 12 launch at Cape Kennedy will probably be remembered as one of the most exciting interactions of weather with a public event in recent times. Thirty-six and one-half seconds after launch, at an altitude of 2 km, the Saturn V vehicle was struck by lightning. At the same time, no less than four cameras photographed a stroke to ground which hit near the launch pad. The astronauts reported seeing a bright flash, and one later told of "feeling" the stroke. The fuel cells were disconnected from the main power bus, an undervoltage condition prevailed, and numerous alarms and warning lights were activated in the command module. Signal conditioning equipment dropped out for a period of about 60 seconds. About nine temperature and pressure sensors were permanently damaged.

At 52 seconds after launch a second major disturbance occurred. The spacecraft was now at an altitude of 4.2 km, 650 m above the freezing level. This time no visible evidence of lightning was photographed, but a spherics receiver at the ground was saturated. Equipment malfunctions were again noted (battery power was in use at this time), most noteworthy of which was the tumbling of the inertial measurement unit in the spacecraft. Fortunately, the inertial unit was not providing guidance at this time.

There is additional evidence, from an analysis of the telemetry signals, that several other electrical disturbances of smaller magnitude occurred both before and after the two major events.

The analysis which follows was prepared for the Office of Naval Research.

DID THE APOLLO 12 TRIGGER THE LIGHTNING FLASH?

It is important to note that the Apollo 12 was not launched into a thunderstorm, or cumulonimbus cloud. For six hours prior to launch, and for a similar period afterward, no lightning strokes were observed or recorded, and no thunder was heard. Electric field meters in the

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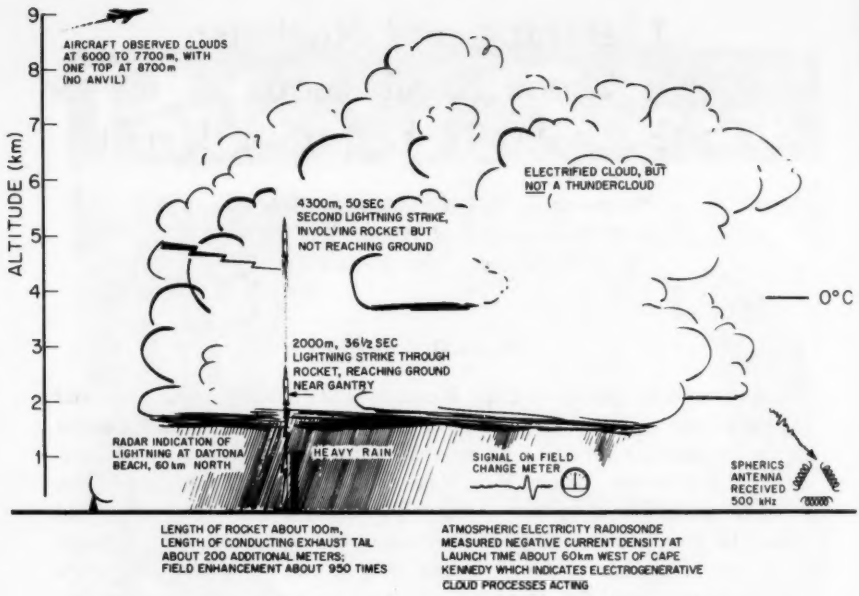
ALTITUDE (km)
9
8
7
6
5
4
3
2
1
AIRCRAFT OBSERVED CLOUDS AT 6000 TO 7700 m, WITH ONE TOP AT 8700 m (NO ANVIL)
ELECTRIFIED CLOUD, BUT NOT A THUNDERCLOUD
4300m, 50 SEC SECOND LIGHTNING STRIKE, INVOLVING ROCKET BUT NOT REACHING GROUND
0°C
2000m, 36½ SEC LIGHTNING STRIKE THROUGH ROCKET, REACHING GROUND NEAR GANTRY
RADAR INDICATION OF LIGHTNING AT DAYTONA BEACH, 60 km NORTH
HEAVY RAIN
SIGNAL ON FIELD CHANGE METER
SPHERICS ANTENNA RECEIVED 500 kHz
LENGTH OF ROCKET ABOUT 100m, LENGTH OF CONDUCTING EXHAUST TAIL ABOUT 200 ADDITIONAL METERS; FIELD ENHANCEMENT ABOUT 950 TIMES
ATMOSPHERIC ELECTRICITY RADIOSONDE MEASURED NEGATIVE CURRENT DENSITY AT LAUNCH TIME ABOUT 60km WEST OF CAPE KENNEDY WHICH INDICATES ELECTROGENERATIVE CLOUD PROCESSES ACTING

Figure 1 – Electrical phenomena–Apollo 12 launch, November 14, 1969

area registered electric field magnitudes which are indicative of disturbed weather, but the lightning flash counter at nearby Patrick AFB showed no strokes except the one associated with the lightning at 36.5 seconds after launch. It is most probable, therefore, that the passage of the vehicle through an electrified cloud incapable of producing lightning on its own, triggered the lightning flashes at 36.5 seconds and 50 seconds after launch (Figure 1).

The Apollo 12 event brings to mind a similar occurrence involving the testing of depth charges by the Navy in Chesapeake Bay (Young, 1961). In this instance, a plume of water thrown up by the explosion to a height of about 80 meters triggered a lightning discharge from the cloud above. Additional triggered lightning events have been reported associated with underwater explosions during offshore seismic explorations. A more complete description of the Chesapeake Bay event, along with a description of laboratory experiments of simulated triggered lightning has been published (Brook *et al,* 1961).

The Apollo 12 and Chesapeake Bay events cover the two most important situations which may be encountered in Naval Operations under electrified clouds. The similarity of the rapid emergence of a water plume to the launching of a Polaris missile is obvious. An aircraft flying through an electrified cloud would be expected to interact with the cloud in a manner similar to the Apollo 12 event. (An excellent

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analysis entitled "Electrical Behavior of an Airplane in a Thunderstorm" has been prepared for the Federal Aviation Agency by Bernard Vonnegut, 1965.) Whether or not the lightning, once triggered, reaches ground, and thereby exposes the rocket or aircraft to the destructive current and rate of rise of current observed in return strokes, does not depend on the vehicle, but depends primarily on the electrical conditions existing in the cloud. We shall discuss some of these considerations in what follows.

SOME PROPERTIES OF LIGHTNING

For purposes of this report, and in the interests of brevity, we shall classify lightning discharges into three types.

1. *Intracloud lightning.* Lightning which does not connect to ground, although dissipating amounts of electric charge and energy similar to those that do, does not generally involve currents greater than 1000 to 2000 amperes with maximum rates of rise probably not exceeding 100-500 amperes per microsecond. The average total duration of these currents does not exceed 3 milliseconds.

2. *Discrete lightning strokes to ground.* Lightning which reaches ground involves a low current leader followed by a return stroke with an average peak current value of 20,000 amperes, and with a rate of rise of about 10,000 amp/micro sec. Currents as high as 100,000 amperes have been recorded. The current falls to half value in about 40 microseconds and is essentially at zero value after several hundred microseconds. On the average, there are about 3 or 4 strokes to each discharge, with a time between strokes of about 40 milliseconds. The first stroke in a discharge usually carries the largest current.

3. *Long continuing-current lightning strokes to ground.* About one out of 5 or 6 strokes to ground is initiated by a leader followed by a discrete return stroke in which the current does not fall to zero value after a few hundred microseconds, but which continues at an average current value of about 185 amperes for an average duration of about 175 milliseconds. Continuing currents of 250 amperes lasting for about 0.25 sec are not uncommon.

Summarizing, high currents and high rates of rise of current are not expected from intracloud strokes; rates of rise of the order of 10,000 amp/microsecond are to be expected from discrete return strokes, each involving from 1 to 5 coulombs of charge; long continuing-current strokes involve high rates of rise as well as persistent currents of about 185 amperes for periods of about 0.2 sec bringing from 12 to 40 coulombs of charge to earth. In terms of energy, the continuing currents involve at least an order of magnitude greater energy release than do ordinary discrete return strokes.

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THE NATURE OF THE LIGHTNING STROKES TRIGGERED BY APOLLO 12 AND BY THE UNDERWATER EXPLOSION

The underwater explosion and the Apollo 12 are unique events in that data on the duration of the strokes are available from movie film. In the case of Apollo 12, at least seven successive frames of the TV video camera film show the return stroke channel fully illuminated. The exposure time for each frame was 1/60 sec, and the time between frames was 1 msec. Although it is possible that each frame recorded a separate, discrete stroke, such an event appears to us to be highly improbable. We believe that the stroke triggered by the Apollo spacecraft was a long continuing current stroke, and that about 20 coulombs of charge passed through the vehicle structure in 0.12 seconds.

In the case of the triggered stroke in Chesapeake Bay, the evidence is again very strong that the discharge involved two or three long continuing current strokes. In this instance, the luminosity persisted throughout 65 frames taken at a rate of 64 frames per second. The duration of this current was somewhat greater than 1 sec, and probably involved a total charge of 100 coulombs or more.

The greatest body of evidence that triggered lightning over water usually involves long continuing currents derives from a series of experiments performed by the group under the direction of M. M. Newman of the Lightning and Transients Institute. Newman's group was successful in triggering lightning over the ocean by firing small, wire-trailing rockets into electrified clouds. They succeeded in "calling down" lightning in 17 out of 23 tries: most notable was the observation that the rocket was usually only about one fifth of the distance from the ship to the cloud base when the lightning occurred. Current measurements and photographs were taken of a specially prepared spark gap in the hold of the ship, and most of the triggered lightning currents were of the continuing current type.

It is probably unsound to conclude, on the basis of only a few events, that triggered lightning discharges to ground tend to be continuing current discharges. But other considerations also favor this view. Without going into too much detail, we point out that discrete lightning discharges must originate from regions of relatively high charge density, for the linear dimension of the charged volume appears to be of the order of 300 to 500 meters. Similar measurements on continuing current discharges give values for the linear dimension about 3 or 4 times greater. Since the volume may be taken proportional to the cube of the linear dimension, cloud volumes associated with continuing currents are about 30 to 50 times greater than volumes storing charge for discrete strokes. On the other hand, the ratio of the charges in continuing currents to discrete strokes is measured to be from 2:1 to 6:1. Assuming that the charged volumes are at approximately the same potential, the capacity

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of the volume drained by the continuing current is approximately 3 times as large, consistent with the 2 to 6 times greater charge stored. But the currents are roughly in the ratio of 1:50, *i.e.*, the discrete currents are fifty times larger than the continuing currents. It is therefore reasonable to assume that the effective impedance of the current source is approximately proportional to the volume in which it is stored. It is this consideration which leads us to believe that triggered lightning probably involves volumes of charge whose density is considerably *below* that which would lead to a natural discharge, and would therefore exhibit a current consistent with the notion of a high internal impedance.

There is obviously much about long continuing-current lightning and the disposition of charge in clouds that we do not understand. But one fact regarding the effective destructive potential of the long continuing currents is known. It has recently been shown, through correlated photographic and electric field measurements, that the long continuing current strokes are the prime cause of lightning-associated forest fires. Not only do they exhibit high rates of current rise in their initial phase, but they persist long enough to cause considerable I^2R heating damage.

ON THE MECHANISM OF TRIGGERING LIGHTNING DISCHARGES

There is no doubt that considerable ionization is present in the high temperature gases; the important question is how long do free electrons persist in sufficient numbers to render the exhaust gases conducting in the appropriate sense. In lightning return strokes, where the temperature may reach 30,000°K, the air is almost fully ionized, and electron densities decay to values of approximately 10^8 m^{-3} in about 50 milliseconds. The reason they persist for so long a time is that recombination is slow until the channel cools to about 3000°K. The temperature in a rocket exhaust is about a factor of 5 or 6 less than in the lightning channel, and one expects therefore that free electron densities are initially very much less, and that their lifetime will also be much less.* At any rate, one can estimate with confidence that electron densities will effectively be zero after a time of the order of ten milliseconds following combustion. Certainly, in this sense, the absence of luminosity should be a good sign of the absence of free electrons.

On the other hand, there is no doubt that the rocket exhaust leaves behind a trail of small and large ions, and that the net charge in this trail is probably not zero. But these ions cannot be thought of as constituting a conductor in the same sense as free electrons, since the mobility of the ions is more than an order of magnitude less than that of free electrons.

The presence of tons of particulate matter in the exhaust trail may influence the path of a lightning stroke in other ways: The net space

*Because of the lower temperature the recombination rate is higher.

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charge left behind on combustion products may influence the course of the leader by providing an attractive or repulsive electric field. Also, the presence of materials in the exhaust may lower the ionization potential of the air by acting as a "sensitizer." For example, sodium has an ionization potential of 5.12 eV as compared to nitrogen or oxygen atomic or molecular species which ionize at from 12 to 15 eV. If the mechanism of progression of the leader involves photoelectric ionization ahead of it, then the lightning leader may be "led" down the exhaust trail in this way.

In general, one need not look for exotic mechanisms by which to trigger a lightning discharge if even moderate electric fields are present, such as are found in many electrified clouds not producing lightning. Consider a rocket such as the Saturn V, which is itself more than 100 meters long, and the luminous exhaust tail which at low altitudes appears to be at least 4 or 5 times the length of the vehicle. About 600 meters is probably a good estimate for the total effective length of this conductor. If a thin conductor of this length is injected rapidly into a region of electric field, it will tend to concentrate the field lines at its extremities, and if the concentration factor is large enough, the electric field at these points will exceed the breakdown field of air. The conductor will then go into corona, and if the electric field is strong enough, the corona streamers will continue to propagate out along the field lines.

To estimate the concentration factor of a long conductor in a uniform electric field, we can approximate its shape by a prolate spheroid (football). The problem is then one of finding the electric field distribution at the surface of the conductor extremities in terms of the ambient electric field E_0. For a vehicle such as the Apollo 12 plus its luminous tail, we calculate that the electric field at the tip of the rocket head is given approximately by

$$E = E_0 \left\{ (n_0)(n_0^2 - 1) \left[\frac{1}{2} \ln \left(\frac{n_0 + 1}{n_0 - 1} \right) - \frac{1}{n_0} \right] \right\}^{-1},$$

where $n_0 = (1 - b^2/c^2)^{-1/2}$, and b and c are the semiminor and semimajor axes of the prolate spheroid, respectively. Setting E equal to the breakdown field E_{br}, the ambient field E_0 becomes the critical field E_c at which breakdown ensues. Thus $KE_c = E_{br}$, where the enhancement or concentration factor K is given by

$$K = \left\{ (n_0)(n_0^2 - 1) \left[\frac{1}{2} \ln \left(\frac{n_0 + 1}{n_0 - 1} \right) - \frac{1}{n_0} \right] \right\}^{-1}.$$

Figure 2 is an example of how the spheroid concentrates electric field lines at its tip.

In Table 1, we have listed the critical field values corresponding to dimensions of rocket vehicles such as Apollo 12, and to other smaller vehicles which may be deployed in various naval operations.

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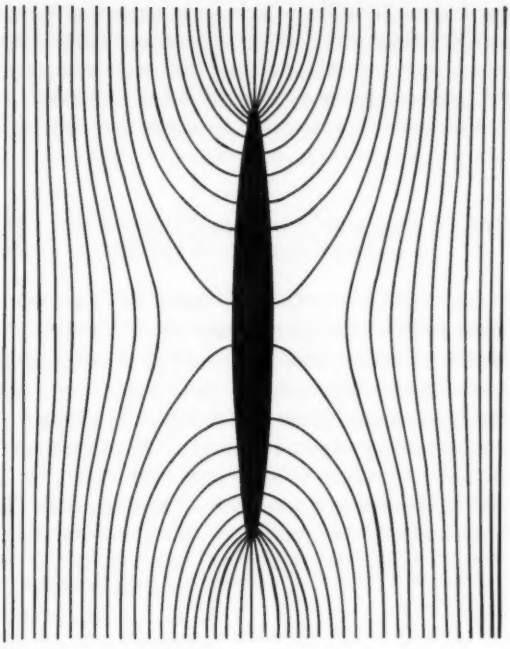

Figure 2 — Uniform electric field distorted by a conducting ellipsoid

TABLE 1

Concentration factor $E/E_0 = K$, critical field E_c, for equivalent semimajor axis c, and semiminor axis b, at a pressure altitude of 2 km, where the breakdown field is assumed to be 2.4×10^6 V/m.

c (meters)	b (meters)	$E/E_0 = K$	E_{crit} (volts/meter)
11	1	57	42000
27	0.5	790	3000
100*	5*	320*	7500*
300	5	950	2500

*The Apollo 12 was capped with a hemisphere of radius 10 cm. This curvature is greater than the maximum curvature for the ellipsoid assumed. Both the concentration factor K and the critical field E_{crit} were calculated in this instance using the higher value for the curvature. The maximum curvature at the tip of a prolate spheroid is related to the c/b ratio by $c/r = c^2/b^2$, where r is the radius at the tip.

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Field values larger than 2000 V/m have been reported for clouds only several thousand feet thick. We see clearly from Table 1 that a long conductor injected into an electric field of only moderate intensity (2500 V/m) will concentrate the lines of force sufficient to produce breakdown. Magnitudes of electric fields observed in clouds are discussed in another section.

$$K = E_{tip}/E_{undisturbed} = \left\{ n(n^2 - 1) \left[\frac{1}{2} \ln \frac{n+1}{n-1} - \frac{1}{n} \right] \right\}^{-1}$$

where $n = [1 - r/c]^{-1/2} = [1 - b^2/c^2]^{-1/2}$ and b and c are the semiminor and semimajor axes of the ellipsoid respectively.

For the benefit of the reader who may want to calculate enhancement factors for c/b ratios other than those given in Table 1, we have plotted in Figure 3 a curve of enhancement factor K *vs* the ratios $c/r \equiv c^2/b^2$. Here r is the radius of curvature at the ends of the prolate spheroid.

When an exposed conductor at rest emits corona, a space charge which reduces the field is formed around the emitting point. This screening effect is counteracted by any motion of the air surrounding this point

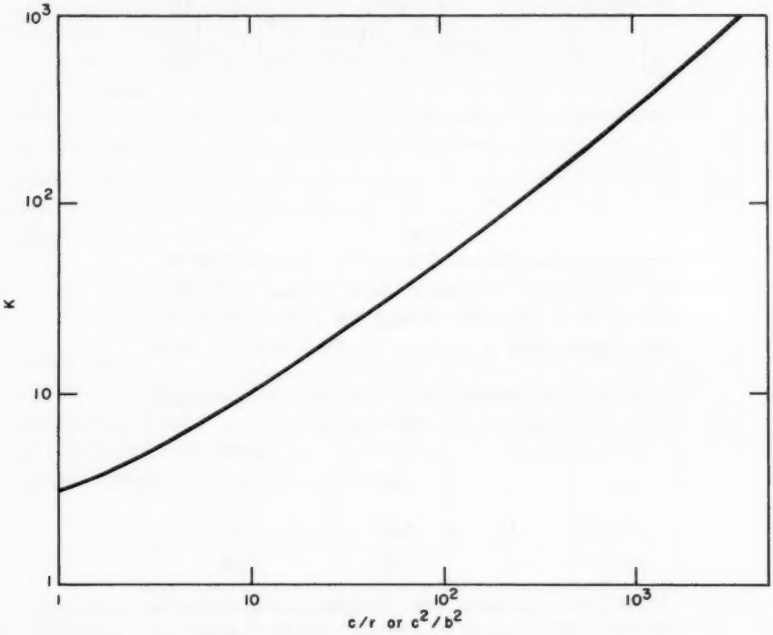

Figure 3 — The electric field enhancement factor "K" at the top of a vertical, prolate ellipsoid versus the ratio of the height of the half ellipsoid c to the radius of curvature of the tip, r

which carries away the space charge and thus reduces its influence on the field at the point. If the relative velocity between air and point becomes greater than the electron drift velocities, *i.e.*, larger than 100 m/s, the field strength penetrates in full force to the emitting point, and the chances of initiating a lightning discharge are increased. Such speeds may occur due to wind and/or due to the velocity of the ascending rocket.

ON THE CHARGE AND ENERGY AVAILABLE FROM A CLOUD VOLUME

Whether or not a vehicle such as Saturn V will become involved in a lightning discharge depends also upon the amount of charge stored in the neighboring cloud volume. We have seen that the initiation of corona is highly probable in moderate electric fields; once corona occurs the discharge will continue if the charge density at the tip of the streamer, and hence the electric field, can be maintained at a high enough value. Once a streamer forms and propagates into the charged volume, another streamer will also propagate from the other end of the vehicle. The formation of a streamer and the maintenance of a breakdown field at the streamer tip requires that charge be continually fed into the growing streamer to charge its increasing capacity. If the cloud capacity is large enough, the flow of charge from it necessary to maintain the breakdown field at the streamer tip will not lower appreciably the potential of the region, and the developing streamer will be led along the lines of force to either another charged volume of opposite sign in the cloud, or to ground. On the other hand, if the amount of charge available or remaining in the cloud is not sufficient to maintain the streamer tips at breakdown, the discharge will cease.

Numerous investigations have been made on the amount of electrical energy which various types of structures can withstand without damage, and these values are well known to engineers. The energies shown in

TABLE 2

Energy W, in joules, stored as space charge in a spherical volume of cloud of radius a, with electric field, E_a, at its surface.*

E_a (V/meter)	a (meters)	W (joules)
100	10^2	0.66
100	3×10^2	18
100	10^3	6.7×10^2
100	3×10^3	1.8×10^4
10^4	10^2	6.7×10^3
10^4	3×10^2	1.8×10^5
10^4	10^3	6.7×10^6
10^4	3×10^3	1.8×10^8
10^6	3×10^2	1.8×10^9
10^6	5×10^2	8.1×10^9
3×10^6	3×10^2	1.6×10^{10}
3×10^6	5×10^2	7.5×10^{10}

*Natural lightning stroke energies are in the range of 10^8 to 10^{10} joules.

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Table 2 have been calculated as available from a volume of cloud for various electric field values at its surface. For simplicity, a volume of uniform charge density in the form of a sphere of radius a has been assumed.

THE EFFECT OF CHARGE ON THE ROCKET IN THE ABSENCE OF AN EXTERNAL ELECTRIC FIELD

To calculate the maximum charge a rocket can acquire in the absence of an external electric field we consider only the extreme case of a rocket without conducting exhaust tail. Such charging of a rocket may be caused by various mechanisms. In all cases, charge increase will stop when the local electric field at the point of the largest curvature exceeds the breakdown field.

We can estimate the total energy available under these conditions from an estimate of the capacity of the vehicle, using a value of 2.4×10^6 V/m for the breakdown field.

The capacity of a rocket can be estimated by again approximating its shape with a prolate spheroid. The capacity is given approximately by

$$C = 4\pi\epsilon_0 c \, [\text{arc tanh } (1 - b^2/c^2)^{1/2}]^{-1}$$

To find the maximum charge which can be acquired by the rocket we calculate the maximum value of the field at its surface; this value occurs at the ends of the prolate spheroid:

$$Q_{max} = 1.1 \times 10^{-10} E_{max} b^2.$$

where b is in meters and Q in coulombs. E_{max} will be the breakdown field $E_{Br} = 2.4 \times 10^6$ V/m, corresponding to a breakdown at a pressure height of 2 km. Thus, $Q_{max} = 2.64 \times 10^{-4} \, b^2$. The energy which can be stored on the rocket is given by $W = 1/2 \, Q^2/C$.

In Table 3 we give the values calculated for capacity, maximum charge, and maximum energy for the four rocket dimensions assumed previously.

It is obvious that the maximum charge which can be carried by a rocket is trivial compared with the charge transferred by lightning which varies from 3 to 50 coulombs. In addition, the amount of electrical energy stored on a rocket is at least 5 orders of magnitude less than is involved in lightning flashes.

On the other hand, charge stored on a rocket entering a region of electric field will lower the threshold for breakdown and the triggering of lightning. Unfortunately, there are no available measurements of the charge carried by rockets to estimate this effect. Similarly, there are no values available for the atmospheric electric perturbations caused by the firing of a rocket and its passage through the atmosphere.

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TABLE 3

Maximum charge Q, capacity C, and maximum energy W, for effective rocket dimensions c (semimajor axis) and b (semiminor axis).

c (meters)	b (meters)	C (farads)	Q_{max} (coulombs)	W_{max} (joules)
11	1	4×10^{-10}	2.7×10^{-4}	91
27	0.5	6.4×10^{-10}	6.7×10^{-5}	3.5
100	5	3×10^{-9}	6.7×10^{-3}	7500
300	5	7×10^{-9}	6.7×10^{-3}	3200

METHODS OF SENSING HIGH ELECTRIC FIELDS IN CLOUDS

For several reasons, the electric field intensities seen at the earth's surface are generally smaller than those encountered within clouds: The charge within and around clouds usually occurs in both polarities so that the electric field seen at the surface of the earth is the superposition of opposing fields. The observed field intensity therefore usually has an appreciably lower magnitude than that produced by either polarity of charge alone. Furthermore, each charge in the atmosphere and its image within the earth comprise an electric dipole; the intensity of the electric field decreases with the cube of the distance from the observer to the dipole.

Another field reducing effect is the formation of a screening layer of charge at the edge of clouds caused by capture of ions moving from the clear air under the influence of the electric fields produced by charges within the cloud.

For these reasons the electric fields seen at the surface of the solid earth are rarely much in excess of 10^4 V/m even at the time just before lightning occurs nearby. On the other hand, immediately after a discharge, the field may be reversed and exhibit values of 10^5 V/m, decaying in a few seconds to the value observed before lightning occurred.

From various measurements it appears that electric field intensities within electrified clouds may often be as great as several hundred thousand V/m. With data from sparks produced in the laboratory, one would expect that fields as great as 10^6 V/m may be necessary to initiate lightning naturally within such clouds.

To sense the intensity of electric fields within clouds several techniques may be used:

1. Penetrations with instrumented rockets.

Dr. W. P. Winn of the National Center for Atmospheric Research has devised and used successfully electric-field sensitive instruments

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which are carried on spinning rockets to altitudes of about 7 km above sea level. The radial components of any electric field vector produce a displacement current in the rocket. As the rocket rotates a sinusoidal signal is generated which is proportional to the external electric field and essentially is unaffected by charge on the rocket. The signal is telemetered back to earth with a low-power FM transmitter using the rocket itself as the antenna. In preliminary measurements, electric field intensities of up to 7×10^4 V/m have been observed in electrified clouds. The maximum electric fields measured during the same period at the surface of the earth just below these clouds did not exceed 10^4 V/m.

2. Measurements from instrumented aircraft.

Airplanes may be equipped with devices to measure the intensity and direction of the atmospheric electric field, but this is a difficult problem inside thunderstorm clouds. A large part of the difficulty arises from charge that the aircraft acquires in flight by the action of the engines, collisions with particulate matter (aerosol particles, cloud droplets, rain and snow) and by point discharge under high electric fields.

The presence of an airplane distorts and concentrates the atmospheric electric field so that extensive adjustments and calibrations are necessary to use the instruments in clear air. Within electrified clouds the difficulties of interpreting the measurements are even more formidable due to the charge transfers between the moving plane and cloud particles, and, if point discharge occurs from propellers, wing tips, or jet exhausts, the calibrations made in clear air may no longer be valid.

To measure the atmospheric electric fields with an airplane one must provide in essence two field sensing devices for each component of the electric field and then subtract their adjusted outputs. This process requires the installation and operation of 6 field sensing devices for measurement of the 3 field components, although some recent ingenious devices designed by Dr. H. Kasemir of ESSA, Boulder, have reduced this number to three.

Indications of high electric fields within clouds have been obtained with aircraft by Gunn and Fitzgerald who report values as great as 3×10^5 V/m.

3. Balloon-borne sensors.

Many of the difficulties encountered in determination of the electric field intensities within clouds arise from the motion of the vehicle transporting the instruments. These difficulties can be minimized by the use of balloons, free or captive, to carry field measuring devices into electrified clouds. Measurements made in this manner are limited to one region or one penetration of a cloud but this limitation may be acceptable for research purposes.

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During the summer of 1969, C. B. Moore mounted an electric field mill inside a spherical electrode from a Van de Graaff high-voltage supply. The mill was recessed, facing downward, in the re-entrant portion of the electrode so that no sharp points protruded to produce corona at low fields. Signals from the field mill were preserved on a small portable tape recorder also mounted *within* the sphere, thus eliminating the telemetry antenna which is usually a good source of corona. This instrument was carried into electrified clouds beneath a captive balloon and obtained indications of electric field intensities at the surface of the sphere in excess of 1.2×10^6 V/m. The conducting sphere concentrates external fields by a factor of 3; the field intensity indicated also varies with the angle θ that the external field E_0 makes with the suspension axis of the sphere. The resultant of these two factors is to produce an indicated intensity

$$E_{Indicated} = 3E_0 \operatorname{Cos} \theta.$$

Making the appropriate corrections, the measurements indicate undisturbed electric field intensities in the clouds in excess of 4×10^5 V/m.

These measurements with a single mill do not discriminate between the field indication produced by external electric fields and those arising from charge trapped on the spherical electrode, and are hence suspect. New measurements are planned, using two field mills in a configuration which will separate the external field from the field produced by charge on the sphere.

By eliminating most of the conventional sources of corona, reliable values for the electric field within clouds should be forthcoming.

This instrument is not suitable for use in naval operations, but should be invaluable in the collection of information about cloud electrification.

4. Radar sensing of electric fields in rain clouds.

The introduction of measuring instruments into electrified clouds distorts the natural electric fields; often the field intensity measured is limited by the presence of the instrument which itself causes dielectric breakdown of the air and the release of charge resulting in spurious readings. To measure the maximum fields that exist in clouds one needs to sense—remotely and without the introduction of instruments—the presence of the electric field within clouds.

One method now under investigation for accomplishing this is the measurement of the distortion of raindrops in clouds. Raindrops are deformed in the direction of the electric field. Water drops are essentially good conductors containing sufficient charge carriers, even when neutral, to polarize in the presence of a field. The action of the field is to cause positive charge to move in one direction and negative charge to move in the opposite direction. When the field is sufficiently intense these forces

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cause physical deformation of the drop along the field direction such that an elongated drop is produced. If the intensity of the field is increased sufficiently, the drop can actually be disrupted by the action of the electric forces.

The drop distortion in a volume of cloud can be sensed with a radar. A raindrop illuminated by a microwave pulse of electromagnetic radiation reflects or "back-scatters" radiation that is roughly proportional to the drop dimension in the direction of the incident electric vector. If the incident electric vector is rotated through a complete turn about the line of sight, the back scattered radiation will vary in intensity as the direction of the electric vector is first along the maximum drop dimension and then along the minimum dimension. From measurements of the cloud reflectivity and the amplitude of the "cross-polarized" back scatter it appears that the magnitudes and directions of the electric fields in clouds may be inferred by remote means. This procedure has promise, and a radar with polarization diversity is now under construction at New Mexico Tech.

Another radar technique for remote sensing of electric fields is also presently under development. Raindrops are excited into oscillation as they fall, and the changing cross section of a vibrating drop appears as a true amplitude modulation of the back scattered radar signal. This effect has been demonstrated in the laboratory with drops freely suspended in a vertical wind tunnel. The natural frequency of vibration is related to the drop size, surface tension, and also to the electric field, since the electric field produces a stress on the drop surface in opposition to surface tension forces, thus altering the effective spring constant. Studies of how the presence of an electric field alters the drop vibrational frequency are underway. The shift in the drop vibrational spectrum, for example, before and after a lightning stroke, may be used to infer electric field values.

COMPARISON OF CONTINENTAL AND MARITIME ATMOSPHERIC ELECTRIC FIELDS

The energy that can be released by a lightning discharge from an electrified cloud increases with the cloud volume and with the square of the maximum electric field. Over the land the atmospheric electric field measured at the surface is limited by discharge currents arising from grounded points Under high electric fields, exposed conducting points such as grass, trees, and structures concentrate the electric field to such an extent that air around the points becomes ionized. This permits electric currents to flow from the earth and acts to reduce the electric stress. When the electric field intensity exceeds about 1000 or 1500 V/m, currents in excess of one microampere can flow from each point. As a result, electric field intensities in the air near the earth beneath thunder-

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storms are limited and rarely exceed values in excess of 10^4 V/m. Perhaps for this reason repeated attempts at New Mexico Tech to trigger lightning by injecting wire-trailing rockets into thunderstorms over land have been successful. The Apollo 12 vehicle is the only rocket of which we are aware that has triggered lightning at low altitudes over land surfaces.

In contrast to this are the successful initiations of lightning by Dr. M. M. Newman of the Lightning and Transients Institute who fired wire-trailing rockets from a small vessel off the Florida coast. The resulting lightning was often initiated when the rocket was no higher than 100 meters above the water, with the cloud base at about 1500 meters. This suggests to us the existence of a high electric stress over the water surface, which means that triggered lightning is highly probable before a rocket enters the electrified cloud.

It is even perhaps worth noting that evidence is also available from antiquity that indicates the presence of especially high electric fields over water surfaces during disturbed weather: St. Elmo's fire is one result of intense point discharge. It is true that point discharge can occur without much visible luminosity, but noticeable St. Elmo's fire is indicative of intense point discharge and very high electric fields.

Our measurements of the point discharge currents from the mast of an LSM operating on the Atlantic Missile Range indicate values that are ten times those flowing from a similar installation on the beach of Grand Bahama Island. From these observations we may infer that the electric field intensities under thunderstorms over water surfaces are similarly enhanced. To investigate this effect further, we have attempted the direct measurement of electric fields beneath thunderstorms over the ocean with instrumented aircraft. The field intensities encountered were much higher than those over land, but the data were confused by saturation of the measuring instruments in the very high fields and by the effects of splashing raindrops which charged the aircraft.

Better measurements are needed, but we know enough to state that the potential for the triggering of lightning and for the release of stored charge is much higher over the oceans than it is over land. For this reason, a large rocket injected from beneath a water surface into a region of high electric field has a high probability of initiating lightning and becoming part of the conducting channel.

The apparent absence of corona points over the ocean surface probably accounts for the existence of high fields, but there is no adequate description of the atmospheric electric processes over the ocean during disturbed weather. In general, little is known about thunderstorms over oceans: we know nothing about the distribution of charge or the polarity. In addition, we don't know whether such thunderstorms are electrically more vigorous because of the low point discharge emission, or whether they are less vigorous because of it.

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The atmospheric electric state produced by convective clouds over the water and its possible effects on ocean launching sites can at best be a subject of speculation at the present time. Definitive studies in electrified clouds and in the air above the oceans are sorely needed. Such studies should include instrumented aircraft flights over, through, and under clouds, instrumented rocket penetrations, and studies of the sequence of electrical events as seen from the surface beneath oceanic thunderstorms. Measurements of the visual and radar thickness of clouds should be correlated with the electric field and other measurements to help develop criteria useful for establishing minimum hazard situations.

SUGGESTIONS FOR MINIMIZING HAZARDS IN OPERATIONAL PROCEDURES UNDER ELECTRIFIED CLOUDS

1. On the basis of the Apollo 12 experience, it is mandatory that the electronic sensing and computing elements of guidance systems be made immune to lightning transients.
2. Although no lower limit to cloud thickness can presently be given, we might guess that vehicle penetration into clouds less than 1700 to 2500 m thick constitutes a minimal hazard situation.
3. Whenever possible, probing by aircraft or small sensing rocket penetration into clouds thicker than 1500 m should precede vehicle launches.
4. Whenever possible, radar evaluation of rate of echo growth as a measure of potential convective and electrical activity should be made.
5. Short range sferics detectors and lightning flash counters should be employed to warn of the occurrence of nearby lightning. Lightning transients may be detectable even from below the ocean surface.
6. The measurement of point discharge current at the surface (as a simple means of detecting high electric fields before lightning has occurred) should be made in all cases when clouds are present.
7. All the electrical measurements should be supplemented and coordinated with a detailed analysis of the synoptic situation.

It must always be remembered that the existence of an electric charge separation process in clouds which exhibits lightning is highly probable for clouds of 1500 m or more thick, and will always pose a severe hazard to rocket launching. This hazard is particularly dangerous since the electrification of such clouds is much more difficult to detect than in the case of thunderstorms.

SUGGESTION FOR DESIRABLE STUDIES

1. Development of remote sensing techniques for the study of electric fields in clouds over the ocean must be implemented. The technique of cross polarization analysis of radar returns is promising. Similarly,

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optical polarization measurements of cloud surface reflected light may be indicative of electric fields strong enough to orient crystals near the surface. Such a technique could be utilized both from surface measurements as well as from aircraft. Other means of remote measurements of fields in clouds should be explored. Particular attention should be given to the exploration of new methods suitable to ocean vessel utilization.

2. Further development of small rocket probing techniques is needed. This method may well be the only simple technique available for measuring electric fields in clouds in times of emergency. In addition to the development of instrumentation, a program using these rockets to uncover electric field intensity versus cloud thickness relationships should be undertaken.

3. Lightning triggering experiments over the ocean should be made with the intent of exploring the possibility of relieving the electric stress in clouds prior to a launch. A trailing wire on a rocket might be used. Again, cloud thickness and electric field measurements should be made simultaneously. The nature of the triggered lightning stroke and continuing currents over the ocean should be studied using high-resolution field-change instruments and high-speed cameras.

4. The charge carried on operational vehicles should be measured during test firings, along with the space charge left behind and the conductivity in the rocket exhaust.

5. A determination of the maximum electric fields existing over the ocean surface should be made for all weather conditions. We suggest that, since surface vehicles distort the electric field and often produce corona by their presence, a submarine would be ideal for such measurements. Great care should be taken to eliminate point discharge from the measuring instrument and its support.

6. Laboratory studies, using modeling tanks with water surfaces in various stages of agitation, should be initiated to study the electrical behavior of water surfaces under high electric stress.

7. A very general study of thunderstorm properties over the ocean and how they differ from storms over land is needed. Such information is essential in projecting what we now know about storms over land to ocean situations.

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Whither Research*

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Introduction

As Chief of Naval Research, I am responsible by law for the encouragement, planning, promotion, initiation, and coordination of naval research. My interest, however, is not limited to naval research alone. As a naval officer, as a scientist, and as a citizen, I keep a sharp eye on the strength and scope of the totality of science and technology in the United States and abroad. Currently I am concerned as to what appears to be a strong reaction—a negative reaction—on the part of many people against scientific research in general and the technological applications deriving therefrom. Thus the title of this talk—Whither Research?

Today, I would like to examine the ever-changing environment influencing the conduct of research here and overseas. This involves a brief historical review, a discussion of events leading to the current situation, and finally a look at what the future may have in store for us.

Setting the Stage

Prior to World War II, we were in an era of "little science." Research was carried out by one or, at most, a few investigators. Funding was modest by any standards, and equipment was usually of the "built at home" variety. Government support was generally minimal. University graduate enrollment was small. The military looked to industry for its technological progress except for a few in-house laboratories operating on a relative shoestring. The major research advances were being made abroad.

The years 1939-1945 wrought a tremendous change in the scientific and technical community. The efforts sparked by the Office of Scientific Research and Development in pursuit of war-related technology involved the mobilization of our scientists and engineers from all segments of society. Government laboratories, university centers, and industrial organizations expanded and worked together as a massive triumvirate to produce radar, the proximity fuze, the nuclear bomb, and a host of other capabilities now considered commonplace.

When the war ended, it suddenly became obvious that those involved in this concentrated national research program would return in droves

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to the institutions from whence they came. No plan for their continued utilization in research of broad national interest had been made. However, Vannevar Bush and other science leaders of the day quickly recognized the importance to the country of continued scientific effort. A variety of ideas were proposed and considered. To fill the breech, at an early date the Congress established the Office of Naval Research in 1946. The Atomic Energy Commission was formed in the same year. For some years these two agencies alone sponsored most of the research in the physical sciences performed in the universities and thus kept up the momentum and concept of broad federal sponsorship of science that the war had engendered. The base of government support expanded in the early fifties with the establishment of the National Science Foundation and the creation of other military and non-military federal agencies interested in sponsoring mission-oriented research. University graduate enrollment and facilities expanded to accommodate to this new concept of research support. Government and industrial laboratories were strengthened in this expanded activity as well. The United States suddenly realized it was the world leader in science. Science and scientific research were now acknowledged cornerstones of national military and economic power that would have to be supported for continued security, economic progress, and social well-being.

The Great Leap Forward (1957-1963)

In the post-war years the United States preeminence in science had not been challenged, and we found ourselves in a self-satisfied mood—that is, until October 4, 1957. The launch by the Soviet Union of the first earth orbiting satellite was almost a national crisis for America. Almost overnight we saw a tremendous expansion in scientific and technological effort to "catch up with the Russians." This growth continued for another five to seven years. The National Aeronautics and Space Administration was created in 1958. In the early sixties President Kennedy proposed putting a man on the moon before the end of the decade. There were large increases in defense research and development funding with consequent further growth of government and industrial technical organizations. Science editors of newspapers and periodicals came into prominence. A large national program of science education was developed. The computer came into its own. There were large increases in graduate enrollment in our universities and increased sponsorship of university research over a much broader range of disciplines.

In this process of "total immersion" in science, one saw the ever-increasing influence of the scientist in major national decisions. The Science Advisor to the President, the President's Scientific Advisory Committee, the National Academy of Sciences, and many advisory

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groups made up of technical leaders were looked to by the Congress, the Administration, and the people for advice and consultation on almost any public issue that arose. It was, indeed, or at least appeared to be, the Golden Age of Science.

Examination and Assessment (1963-1969)

Because of the growth of science, a variety of committees in the Congress became involved in studies, legislation, and overview of government activity in very sophisticated technical and scientific areas. Having little scientific training and only limited staff expertise available, it was difficult for the average senator or representative to understand much of the testimony he heard and to adequately assess legislation pertaining to scientific matters. In the early years the tendency was to accept the opinion of experts appearing in support of various bills being heard. However, as the scope of government involvement in research increased each year, there arose a feeling of discontent in our legislative bodies. The increasing influence of scientists in national affairs made it apparent to the Congress it needed expertise of its own so that it could better gage the scope, quality, and significance of scientific matters that came before it.

Initially, it sought the advice of the National Academy of Sciences. The Academy was asked to help determine how much federal support should be provided for basic research and how allocation to the various disciplines should be made. The response, in the form of a book of collected essays entitled "Basic Research and National Goals," was not entirely satisfactory in that it did not answer the specific questions posed. It was helpful in giving an insight into the scientific process and showed that science, too, had its constituencies.

Still dissatisfied with the situation, the various Congressional committees and individual members of the Congress employed or consulted their own science experts. The staff of the Science Policy Research Division of the Legislative Reference Service of the Library of Congress was increased. Gradually, the legislators began to enhance their understanding of science and technology and indeed many have become quite expert. As a result of this increasing sophistication, we have seen much more detailed questioning of witnesses and more serious thought and attention as to the impact of science and research on all aspects of our society.

It was also apparent that the growth rate in support for research enjoyed in the early post-sputnik era could not be fiscally sustained for many more years. At the same time the Congress was beginning to find soft spots in research programs presented for its consideration. More and more, questions were being asked as to the impact of the national research effort and its output on the quality of university

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undergraduate instruction, on the environment, and on society in general. The national involvement in Vietnam, disturbances on many college campuses, and increasing costs of "big science" have all acted to engender in the Congress a feeling of malaise, discontent, and disillusionment with the whole research process.

In the same time frame, attitudes in the executive branch began to change somewhat. There was a feeling that government-sponsored research was not meeting the more immediate needs of society. Thus, we began to see in many federal agencies stricter requirements for statements of relevance and early application of research results in government-sponsored work. There has been a distinct trend toward centralized direction and long range planning of research to meet the problems of health, environment, transportation, education, and communication that have arisen from urban growth.

The colleges and universities had a new generation of junior and intermediate faculty and student bodies that were very vocal on a variety of political issues. The draft and our Southeast Asian involvement gave rise to further reaction on the campuses against science and where it was apparently taking us. Government-sponsored research, especially that of the Department of Defense, was subject to great criticism. Students felt they were deprived of quality instruction because of inordinate professorial involvement in research and research consulting. There was a feeling that our resources were being misdirected into areas of science that had little bearing on what they considered the problems of the day. It should also be noted that, although enrollments were increasing, a diminishing percentage of students were choosing to pursue careers in the sciences, particularly in physics.

Industry, too, had expanded its research activity in the blush of enthusiasm after Sputnik. It was almost fashionable for a company to have a group of young scientists engaged in industrial research. The hope was that by serendipity, inspiration, or chance some major advance of benefit to the organization would be realized. After some years, the bloom started to fade from the rose, and many a business organization drastically reduced its research involvement as too expensive in view of only modest return.

In the first 10 years after World War II the countries of Western Europe had re-established centers of research and had achieved a scientific productivity equal to that enjoyed before the War. In the late 1950's and early 1960's, just as in the United States, interest in research increased and centers of science expanded accordingly. Just as in the United States, however, it is apparent that a reaction began to set in. It was felt by the governments of these countries that science and research were not necessarily responsive to their current needs. In the United Kingdom, after some years of assessment, it was determined that national science and technology effort should be directed to support

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of production of goods going into the overseas trade. A new ministry, the Ministry of Technology, was created to manage this redirection. Its purpose was not only to change the direction and application of research but to encourage scientists to move out of the university environment into industry where their expertise could be more readily applied. Certain national centers involved in long range research were drastically reduced. A prime example was the Culham Laboratory, at the time the world's leading research laboratory in plasma physics, which was cut almost in half. Much more attention was paid by the government to the allocation of support of science in universities. UK support of international research efforts related to space and nuclear energy was cut back as well. France went through much of the same experience. The thrust in the late years of the DeGaulle government lay in the direction of technological application rather than long range research. National priorities in funding were adjusted accordingly. The Italian situation was much the same. Italian industry has done and continues to perform outstanding research, particularly in the field of polymer chemistry. The university situation in Italy is somewhat muddled. It has been difficult for good relationships to be established between the Italian government and its university community. West Germany has identified several areas of research emphasis. These appear, however, to be oriented to early application. One does see a trend away from the pre-war dominance of individual professors in university and state research centers. The Soviet Union had built up a strong basic research capability after World War II. It, too, however, recognized the difficulty in translating research results into technological applications and, therefore, reorganized its science system to emphasize application and to strengthen the ties between its academies and institutions of higher learning and its major industrial effort.

In summary, one can say that in the years ranging from 1963 to 1969 there has been a rather drastic assessment of the research process and its value to a nation's society. The general trend has been to reduce long range fundamental research support in favor of that leading towards more immediate application.

The Pause to Regroup and Reform

Currently, we find ourselves in the process of redirecting our efforts in science and technology in a variety of ways to be more responsive to the needs of the present and what we see as the future. The Congress is making stronger demands for the formulation of a national policy for science. There has been a variety of suggestions from that legislative body with regard to centralization and reorganization of the government science effort. Some would establish a Department of Science and give it the responsibility for all government-funded research. Other proposals

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have been somewhat more modest but focused in the same direction. The old line agencies involved in support of fundamental research are experiencing level or decreased budgets after a most thorough soul-searching and intensive questioning by the Congress. The Department of Defense is cutting down on its research effort. The National Science Foundation has been able to maintain only a level budget. The National Institutes of Health that experienced such growth in the preceding ten years have found it necessary to reduce support of important medical research on a country-wide basis. Our space effort funded for some time at an annual level of five billion dollars is being reduced this year to less than four billion. We do see some new research initiatives in other agencies of the government who have responsibilities more closely related to the social problems of the day. The scientific activities of the Departments of Health, Education and Welfare, Commerce, Transportation and Interior, although modest, are beginning to expand in response to a variety of newly established government initiatives. The new administration has appointed task forces to address many of the problems that we face in order to give direction to the research activity necessary for their solution.

On a national scale what we have come to term "big science" is being questioned. Our space effort is perhaps the prime example. Here the controversy lies between manned and unmanned space effort and some honest differences as to what part of our total national scientific involvement should be directed to space activity. It appears that we have seen the peak in support of nuclear physics research. The costs of equipment necessary to gain new knowledge are becoming so high that such research cannot be supported on the scale heretofore enjoyed. A similar situation obtains in the field of radio astronomy wherein extremely large antennas are required for new knowledge to be gained.

There is increasing concern on the part of all segments of our society as to our environment. The problem of air and water pollution compounds itself exponentially every day with only modest attention being given to it. The Congress has recently held a series of hearings on the topic of technological assessment. Many feel that prior to undertaking a large research initiative an assessment of its impact on environment and on people should be made. The use of DDT as an agricultural pesticide is cited as an example of where such an assessment might have been extremely helpful. Many others have been cited as well. There is an ever increasing interest in the field of oceanography because of the promise of the oceans for food and mineral resources necessary to support an ever increasing population.

At the very same time we see the university community reassessing its relationship to its surroundings. There has been much discussion as to the role of the university; namely, whether it should exist as a center of knowledge and scholarly pursuit thereof or should have the additional

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role of relating to its constituency in a much more direct fashion. This will have an impact on the type of research and investigation that will be performed by faculty and graduate students. We also note that enrollments both in graduate and undergraduate levels continue to increase, at the very same time that government support for education and graduate research is leveling out and decreasing. This is beginning to pose an almost unsolvable problem. Most scientists agree that graduate research is absolutely necessary as a part of the educational process for scientists and engineers. Unless some sort of support is forthcoming, we will not have adequately trained people to carry on the necessary science and technology needed for our continued economic progress. There is a trend in universities toward interdisciplinary research; however, it has been difficult to break down the barriers that have traditionally existed among research-oriented academic departments. Traditional concepts of university administration appear to be changing. Such changes may influence the procedures governing the management of externally funded university research.

Industry is also having its problems. The cut-backs in government support are directly translated into staffing reductions in industry and to companies therein that we look to or will be looking to for the resolution of our increasing problems of environment, transportation, urban development and the like.

Thus, the years of 1970-1971 will be a period of change in which different directions of science and technology will be established. New organizational groupings will come into being. Planning will be more formalized. New legislative approaches may be taken. Only after this period of "shake-down" will the nation be ready for new initiatives in science and technology.

Looking Ahead

The principal determining factor on the directions chosen for scientific effort in the next several decades will be the tremendous population growth. By the year 2000 there will be 300,000,000 Americans, most of whom will be living in urban centers. College enrollments will continue to climb. By 1980, 10,000,000 students will be attending institutions of higher learning as contrasted against 7,500,000 today. All the problems crying for attention today can only be exacerbated by increasing numbers of people.

Air and water pollution control, adequate waste disposal techniques, and the move to exploit the ocean will depend on support of science and engineering pertinent to these areas. We will require funding in excess of those being directed to these areas today. Our already overburdened networks of transportation for both people and goods will require the intensive attention of vehicle and system research capabilities.

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The multitude of social crises that are developing will demand the dedication of resources to support research in a variety of areas. There will be a call for effort directed to universal continuing education; to the prevention of crime and to the rehabilitation of criminals; to clothe, house, and feed our people; and to provide increasingly sophisticated medical care. Tremendous growth in communication and information transfer capability will be necessary, if only to lighten the burden on transportation facilities.

Our problems in numbers of people and the increasing demands for natural resources of the world for their support are not singular to us. Other nations will be experiencing similar difficulties. We will thus be very fortunate if international tensions do not become more evident. As a consequence, we will have a continuing need for a national defense capability, including a base of research and development for its support and currency. We must avoid technological surprise at all costs.

With all these factors in mind, we can get an idea as to the directions research in broad areas of science will be taking in the future. I believe that we shall see a leveling or slower growth rate in support of the traditional physical sciences. Effort in the areas of physics and chemistry will be increasingly directed in support of broader interdisciplinary activity, but the overall magnitude of research will not grow dramatically. Initially, oceanography will lead the way because of its broad base of support from elements of federal, state, and local governments, as well as the investment being made by resource related industries. Geology and geophysics will also grow because of our increasing needs for material resources. The growth in population will place a demand for a "step increase" in the social and behavioral sciences as well as in medicine and biology. We will require major increases in support of the engineering science to provide for the technological application of results of the aforementioned research. One can also expect that the newly identified discipline of management science that includes systems analysis and operations research will grow. This effort will be needed to provide the capstone of management and directive capability needed to plan and direct the resources of money, manpower, and material involved in all of the foregoing.

A Challenge to the College of William and Mary

An institution such as yours located near the sea and one of the major seaports of the country has a wonderful opportunigy for involvement in what can only be a very active thirty years ahead of us. The Newport News-Hampton area and its surroundings offer a wonderful natural laboratory for study, research, and activity by all elements of the College. You have a microcosm, if you will, of all the problems we can foresee in the future but of a size and availability that lends itself to

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examination on a workable basis. There is industry, space effort, a coastal zone, a major estuary, and a center of transportation and shipping. There is an expanding urban population that offers ample chances for studies in education and other social and behavioral disciplines. The College is of such a size that it could conveniently focus its efforts and provide the necessary interdisciplinary coordination to contribute materially to the solution of the problems of our growing society.

Summary

In the brief time available I have attempted to describe the ever-changing environment that surrounds and really governs the scope and direction of scientific research and technological development. We have seen research grow, blossom, and then become subject to the ravages of public opinion and disillusionment. At times it has seemed as not being a question of "whither research?" but rather "whether research?." As educators and professionals, there is a need to tell the story and explain the benefits of scientific effort to the housewife, community business leaders, and elected representatives at local, state, and national levels. Indeed, those involved in research must make every effort to demonstrate the relevance and utility of their work. Although it has had its ups and downs, it is my personal conviction that research has a great future. It has been, is, and will continue to be the foundation on which rests our security, our economy, and the social welfare of our people.

SOFAR Float Program

The SOFAR Float Program is a joint effort by two ONR supported investigators (Dr. Rossby of Yale and Mr. Webb of Woods Hole Oceanographic Institution) to observe and measure deep ocean currents by tracking neutrally buoyant floats in the deep sound channel. In October 1969 a float was launched at 25°N, 69°W. It is now in the fourth month of being tracked and has been telemetering temperature data successfully. It is drifting at approximately 1100 meters depth (calculated from the temperature telemetry), which is some 200m above the axis of the sound channel. The launch point was approximately equidistant from the three MILS tracking stations (Ramey, Puerto Rico; Tudor Hill, Bermuda; and Eleuthera, Bahamas) used to obtain the tracking data to determine the floats position as a function of time. Preliminary analysis of data indicates the float has moved westward some 300 km while making extensive north-south excursions since the launch. A WHOI ship will pass near the float in March and will verify its position and make measurements of temperature, density and sound velocity structure. The successful tracking, now in its fourth month, has demonstrated the feasibility of this technique for measuring deep ocean movements.

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New French Submarine

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A recent issue of *New Scientist* comments on the efforts of the Centre National pour l'Exploitation des Océans and the Institut Francais du Petrole to build a new experimental submarine for underwater exploration. Known as the ARGYRONÈTE (water-spider), the vessel will combine the function of a submarine, and underwater house, and a decompression chamber.

The submarine will be divided into "dry" and "wet" compartments. The larger dry section can be kept at atmospheric pressure and houses the engine and normal crew facilities. The wet section, which will occupy approximately one-third of the vessel's total length, forms the underwater house and decompression chamber. Here there will be room for four divers, to be supplied with a special breathing mixture, enabling them to live and work in a pressure equal to that of the outside environment. When the work is completed, the divers would then go through the decompression process in this compartment while the submarine is returning to its home base. Apart from the four divers, the submarine is being designed to carry six crewmen. A spherical compartment in the conning tower is designed to provide emergency escape system. If the submarine should run into difficulties, the entire crew could enter the sphere which would then be released from its housing and float to the surface.

The article points out that the main value of a submarine like ARGYRONÈTE lies in the fact that it will enable men to work for long periods on the ocean bed. They speculate that eventually it may be possible for divers to explore the edge of the continental shelf, and the ARGYRONÈTE is designed for a capability of just under 2000 feet. The vessel measures approximately 90 feet in length by 9 feet in height and 7 feet in width, and will have a total displacement of 250 tons. It is hoped that the vessel will come into service some time early in 1972. The article points out that the United States has already built three "wet" and "dry" submarines but that they are much smaller and have a far more limited range, while the new French vessel is purported to have a considerably greater range, a higher speed, and will be much cheaper to build. It will be able to travel 450 miles on the surface at a speed of about six knots and will remain submerged on the ocean bed from three to eight days. The cost of the submarine is estimated to be about $3.6 million to be shared equally by the Centre National pour l'Exploitation des Océans and the Institut Francais du Petrole.

NRL Scientist Receives Award

Mr. Carlyle V. Parker, an electronics researcher at the Naval Research Laboratory, has been presented the Navy Distinguished Civilian Service Award for his contributions toward the development of a Secure Identification System. The Electronics System, called the Mark XII, is used to identify friend or foe in aircraft or other vehicles and is a vital defense tool. Captain James C. Matheson, in behalf of the Secretary of the Navy, conferred the award upon Mr. Parker in ceremonies held at the Naval Research Laboratory. Mr. Parker is Head of the Security Systems Branch, Electronics Division at the Laboratory.

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Research Notes

Development of an Advanced Time-Sharing System at M.I.T.

Interest both in alleviating deficiencies in its own CTSS developed Time-Sharing System (Compatible Time-Sharing System), and in removing the limitations of the commercially available systems led, in the past three years, to an extension of time-sharing research at M.I.T. This extension of expansion, called MULTICS (Multiplexed Information and Computing Service), had the objective of explicitly defining all of the desirable features of an idealized time-sharing system along with an effort to build a system which would simultaneously encompass all of these sought after capabilities. Of major interest is the accomplishment that this prototype system (initially servicing approximately 40 users, but with customer expansion capabilities) was demonstrated to be operationally acceptable in November 1969. Equally important, if not as dramatic, this same program produced literally hundreds of technical papers whose widespread dissemination have had a tremendous effect on university and commercial time-sharing research. Again, the most interesting aspect of this development is its incorporation of a multiplicity of desirable features in a single, proven system. Those features which are most significant from the user's perspective are described below: (1) improvement in reliability through establishment of a capability for running continuously seven days a week, 24 hours a day; this level of reliability is essential to realizing the goal of time-sharing centers functioning as large scale computer utilities, (2) provision of a capability for automatic recovery of data in the event of loss or damage to files, (3) sophisticated control over user access to the system, to files and to unique combinations of files and data elements within the system, (4) improvements in access and processing speeds through exploitation of multi-programming and parallel processing techniques; techniques which permit a single processor or combination of processors to simultaneously perform a multiplicity of logical operations, (5) automatic cost-accounting and billing for use of computer time by the system customers, (6) simplified language development to improve use of time-sharing services by the non-programmer, (7) system flexibility, through modular design, to: (a) accommodate expansions in numbers of users and/or central processor without the necessity for major revisions to the system software, (b) permit automatic reconfiguration of the system's hardware/software assets tailored to individual user needs, and (8) incorporation of a "virtual memory" approach for users requiring a very large addressable memory; virtual memory consisting of a high performance paging drum which provides such rapid and selective core and secondary storage interation that "memory" effectively is constrained only by the totality of secondary storage (drums, discs, *etc.*) attached to the system.

Freeze-Dried Skin Aids Burn Casualties

The use of freeze-dried skin grafts, furnished by the Navy Tissue Bank, has caused a reduction of 26 percent in expected mortality in burn patients. The major improvement over expected mortality occurred in patients with burns covering 33 to 62 percent of their surface area. The skin grafts are obtained under surgically sterile conditions from cadavers and are stored by the tissue bank so that a supply is readily available for emergency situations. The freeze-dried grafts have been shown to possess almost the same quality as fresh homografts and to be superior to tissues preserved by other techniques.

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Themis Study of Stress Biochemistry

A team of reviewers from ONR, the ONR Branch Offices and NMRI visited Hahnemann Medical School in Philadelphia to check on progress since the 1 July initiation of this Themis contract. It was agreed by all observers that the program is off to a very good beginning.

Some equipment is still not available. Nevertheless, interesting work is in progress and some results are beginning to be found. Eleven separate research efforts were reported on, ranging from studies of liver and heart metabolism following severe hemorrhage in dogs to the relative effectiveness of exercise taken standing up and lying down as conditioning for future stress. Contrary to expectations, the exercise in the horizontal position seemed to provide as adequate conditioning, at less physiological cost to the individual.

The group is truly interdisciplinary, though centered about cardiac physiology and metabolism, and is also truly coordinated and cooperating, both within itself and with the Stress Biochemistry Group centered about the Navy In-house studies, including a related Themis project at the University of Oklahoma Medical Center. The biochemical basis for the physiological effects of stresses due to heat, exercise and wounding may well be established by this group of investigators within the next decade or less.

Proof of the Law of Diminishing Returns

Professor Ronald W. Shephard, an ONR contractor, University of California at Berkeley has made a fundamental contribution to mathematical economics in his recently issued report, "Proof of the Law of Diminishing Returns."

For 200 years, since it was first expressed (for land) by the French economist Anne Robert Jaques Turgot (1767), a law of diminishing returns in the physical output of production has played a central role in the marginal analysis of economic theory. Roughly the law states that the output from production will eventually suffer decreasing increments or decreasing average return if the inputs of some factors of production are fixed, and others are increased indefinitely by some equal increments. Divorced of its reference solely to agriculture, diminishing returns are taken as a fundamental law for technology to support economic theories of equilibrium and price determination.

Historically, there has been considerable confusion in the statements of the law and the arguments adduced from it, involving some of the most emminent classical economists. With the introduction of the notion of a production function about 1910, deductions (explanations) of the law have followed from mathematical properties assumed for the production function. Since the law of diminishing returns is a statement concerning technology, (from which the production function is a derived concept) a study of the logical relationship between statements of the law and basic concepts in the theory of production should start with a mathematical definition of a technology. Professor Shephard's contribution consists in deriving the law in a mathematical framework beginning with a precise definition of a technology.

The kind of mathematical thinking in economic contexts examplified by Professor Shephard's paper is related to a variety of Navy support activities, in particular logistic control problems and the management of Navy industrial-type activities.

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On the Naval Research Reserve

NRRC 1-1, Boston, Massachusetts

The Charles Stark Draper Laboratory—known until recently as the M.I.T. Instrumentation Laboratory—was host to thirty Research Reservists. During the seminar, sponsored by NRRC 1-1, the reservists were briefed on the major programs of the Laboratory. These programs include the navigation, guidance, and control systems for the Navy's Poseidon missile and Deep Submergence Rescue Vehicle, and for Apollo. In addition, reservists were briefed on the theory of inertial guidance, and on new developments in the construction of inerital measurement units, including gimbal-less mounting techniques, and high precision gyroscopes and accelerometers.

The Draper Laboratory makes extensive use of cockput simulators for training of crews and development of guidance and control computer programs. By means of these simulators, reservists were given the opportunity to "fly" an Apollo command module into and out of lunar orbit, and to "land" a simulated full-size Lunar Module on the moon's surface.

NRRC 3-1, New York, New York

During the past year several reservists in NRRC 3-1 have taken on-the-job training. This has, however, really been in the form of on-the-job participation. The reservists who have taken this duty came back with good reports because they have made a significant contribution to the naval establishment during their ACDUTRA tour.

A typical tour was completed by CDR Martin Rizack, MC, USNR, at the Naval Medical Research Laboratory in Bethesda. CDR Rizack worked with other medical research personnel studying the problem of oxygen poisoning of blood. He was able to bring to bear his experience as a research scientist and Professor at the Rockefeller Institute to the problems of the Navy, and at the same time was able to bring back his experiences to his students at the Rockefeller Institute.

Another successful tour was completed by LCDR Peter Lederman, USNR, at the Naval Applied Science Laboratory. Dr. Lederman in civilian life is a Professor of Chemical Engineering at the Polytechnic Institute of Brooklyn and a Chemical Engineer. While at NASL he worked closely with the regular full time research personnel in evaluating a new soil stabilization method and suggesting new uses for this method. He also suggested a design for a continuous preparation of the stabilizer. In addition, he made a study of the hazards of light fuels which hopefully will help in establishing the need for further studies in fire protection equipment.

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NRRC 9-2, Urbana, Illinois

Naval Reserve Research Company 9-2, has undertaken a program of field trips to various laboratories on the University of Illinois campus and the surrounding area.

In the fall quarter a trip to the Agricultural Engineering Laboratory was arranged where some hydraulic studies were discussed as well as farm equipment and soil.

During the winter quarter, the unit visited a part of the State of Illinois Natural History Survey. It is a unique, internationally recognized, state-supported research organization which devotes its attention to the study of the living resources, animals and plant life of the state. The Survey seeks to determine the most effective means of protecting and intelligently using them for the maximum economic, educational and recreational benefit of all Illinois citizens. Although not a part of the University of Illinois, its central offices and laboratories are located on the Urbana campus.

The Survey has grown considerably from the days of John Wesley Powell who made his pioneering trip down the Colorado River while the head of one of the Survey's predecessor organizations. Today, the Survey has more than 100 members on its scientific and technical staff from the fields of biology, chemistry, and physics.

The Survey is currently headed by Capt. George Sprugel, Jr., also a member of NRRC 9-2. The visit in January was concerned primarily with the economic entomology section which conducts research on insects of economic importance and on methods for controlling them.

NRRC 9-3

In Ann Arbor, Michigan, Naval Reserve Research Company 9-3 recently observed its 21st birthday. NRRC 9-3 with CDR Charles M. Davis, USNR, at the helm was launched on 14 January 1949, as a Volunteer Research Reserve Unit.

In the early days, as now, NRRC 9-3 was mainly staffed by faculty, staff and students from the University of Michigan. However, many officers are from neighboring industry and private practice. In 1956, under the command of CDR Fred O. Briggson, USNR, NRRC 9-3 was awarded the General Excellence Plaque by the Commandant, Ninth Naval District. The unit also hosted the ONR Seminar on Oceanography in 1967.

NRRC 9-19, Iowa City, Iowa

LT John K. Stille, professor in Chemical Research at the University of Iowa and a member of NRRC 9-19, has developed a new adhesive

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for metal to metal bonding and metal to laminate bonding in supersonic aircraft. Military applications will no doubt result due to the strength of the adhesive at high temperatures. It can be used to bond titanium skin to honeycomb structures as well as providing a bond between the skin and structural members. Dr. Stille's adhesive is a thermally stable polyquinoxaline which becomes even stronger at higher temperatures and has the highest strength value known for an organic adhesive.

NRRC 9-28, Columbia, Missouri

Dr. John S. Spratt, Jr. (CDR MC USNR-R) of NRRC 9-28 has built the seven-year old Cancer Research Center (CRC) into an institution with 75 employees in sections of biomathematics, operations research, biochemistry, administrative support and educational support. Dr. Spratt graduated from the University of Texas Southwestern Medical School in 1952 and had his surgical training at Washington University-Barnes Hospital in St. Louis.

Dr. Spratt is not only director of the CRC but also chief surgeon at the Ellis Fischel State Cancer Hospital, professor of surgery at the University of Missouri Medical School, lecturer in surgery at Washington University School of Medicine in St. Louis, and member of a number of national policy committees for cancer research and teaching.

Dr. Spratt became interested in management science and operations research in clinical medicine partially through his 18 years of association with the Naval Reserve. During this period he has had 12 tours of ACDUTRA and deliberately selects nonmedical tours when possible to augment his basic medical knowledge. He is one of 9 reserve officers from the Ninth Naval District selected to attend the Senior Reserve Officers Course at the Naval War College this summer.

Detection of Hepatitis Carrier State

Data has been obtained by Dr. J. R. Senior to validate the allegation that there is less risk of transmitting hepatitis by transfusions of red blood cells preserved by the freezing process used by the Navy than with blood which has not been frozen. Further work was planned to determine which step in the processing procedure for freezing cells is responsible for inactivation or elimination of the hepatitis agent. However, this work is being influenced by a recent development in the hepatitis field. Other investigators have confirmed the existence of a hepatitis-associated serum antigen. This finding presents the possibility of developing means for the detection of persons who have a minimal hepatitis infection, in which they show no symptoms of inflammation of the liver, but transmit the agent causing such a condition to recipients of their blood. Dr. Senior is reviewing this effort in order to evaluate use of the hepatitis-associated antigen as a diagnostic tool in the selection of blood for transfusion therapy. Should this prove feasible, blood containing hepatitis virus could be identified and not used for transfusion purposes.

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Project SANGUINE, Bio-Medical Subcommittee for ITAG

There has been an increasing concern within the Department of the Navy and by civilian authorities regarding the bio-medical effects of extremely low frequencies (ELF) in the electromagnetic spectrum. Very little is known about such effects on humans, animals and plant life. Since such frequencies would be employed in Project SANGUINE-type installations, some exploratory bio-medical research has already been initiated by the Navy and further research might be required. The Interference Task Advisory Group (ITAG), established by the Navy, is engineering oriented and oversees progress on the project. The ITAG recently determined to have a Bio-Medical Subcommittee to monitor the Navy-sponsored and other pertinent research as well as to function in an advisory capacity. Dr. Leonard M. Libber, Physiology Program Director was appointed Chairman of this Subcommittee.

Improved Method for Measuring Residual Stresses in Surfaces of Metals and Alloys

New understanding has been gained in using improved x-ray methods for determining residual stresses in metal surfaces. It is used to nondestructively find stress conditions for critical components, such as helicopter blades for Navy and others. Professor J. B. Cohen of Northwestern University applies new techniques involving Fourier analysis (a mathematical analysis of x-ray line broadening) to grain deformation in metals as a function of stress variables both internally and on the surface.

People at Caterpillar Tractor Company and others at Vanderbilt University have applied his analysis of obtained x-ray peaks with good success in detecting other possible reasons of stress anomalies after rapid engine shut-down. Based on new assumptions (beyond metal surface texture presences) internal "fine structure" faulting involving interstitial stressing of metal components of which helicopter propeller blades cited are only one example.

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